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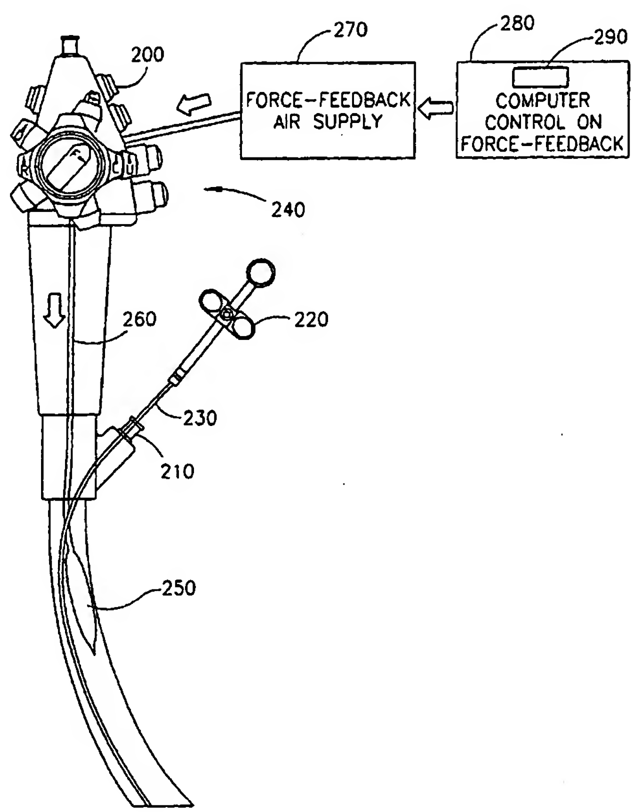
(54) Title: TOOLS FOR ENDOSCOPIC TUTORIAL SYSTEM



(57) Abstract: A tool for use with a system for simulating the minimally invasive medical procedure of endoscopy, particularly of flexible gastroendoscopy. The tools support the close simulation of the actual medical procedure of endoscopy by simulating medical instruments in the context of providing tactile and visual feedback as the simulated procedure is performed on the simulated patient.

WO 01/88881 A2

WO 01/88881 A2

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TOOLS FOR ENDOSCOPIC TUTORIAL SYSTEM

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to tools for teaching and training students in medical procedures, and in particular to the use of such tools for training students in the procedure of endoscopy, in which the tools are able to simulate force feedback provided during the performance of the actual medical procedure on a living subject.

Endoscopy, and in particular flexible gastro-endoscopy, are examples of minimally invasive medical procedures. Flexible gastro-endoscopy is an important medical tool for both surgical and diagnostic procedures in the gastro-intestinal tract. Essentially, gastro-endoscopy is performed by inserting an endoscope, which is a flexible tube, into the gastro-intestinal tract, either through the mouth or the rectum of the subject. The tube is manipulated by a trained physician through specialized controls. The end of the tube which is inserted into the subject contains a camera and one or more surgical tools, such as a clipper for removing tissue samples from the gastro-intestinal tract. The physician must maneuver the tube according to images of the gastro-intestinal tract received from the camera and displayed on a video screen. The lack of direct visual feedback from the gastro-intestinal tract is one factor which renders endoscopy a complex and difficult procedure to master. Such lack of feedback also increases the difficulty of hand-eye coordination and correct manipulation of the endoscopic device. Thus, flexible gastro-endoscopy is a difficult procedure to both perform and to learn.

Currently, students are taught to perform flexible gastro-endoscopy according to the traditional model for medical education, in which students observe and assist more experienced physicians. Unfortunately, such observation alone cannot provide the necessary training for such complicated medical procedures. Students may also perform procedures on animals and human cadavers, neither of which replicates the visual and tactile sensations of a live human patient. Thus, traditional medical training is not adequate for modern technologically complex medical procedures.

In an attempt to provide more realistic medical training for such procedures, simulation devices have been developed which attempt to replicate the tactile sensations and/or visual feedback for these procedures, in order to provide improved medical training without endangering human patients. An example of such a

simulation device is disclosed in U.S. Patent No. 5,403,191, in which the disclosed device is a box containing simulated human organs. Various surgical laparoscopic procedures can be performed on the simulated organs. Visual feedback is provided by a system of mirrors. However, the system of both visual and tactile feedback is primitive in this device, and does not provide a true representation of the visual and tactile sensations which would accompany such surgical procedures in a human patient. Furthermore, the box itself is not a realistic representation of the three-dimensional structure of a human patient. Thus, the disclosed device is lacking in many important aspects and fails to meet the needs of a medical simulation device.

Attempts to provide a more realistic experience from a medical simulation devices are disclosed in PCT Patent Application Nos. WO 96/16389 and WO 95/02233. Both of these applications disclose a device for providing a simulation of the surgical procedure of laparoscopy. Both devices include a mannequin in the shape of a human torso, with various points at which simulated surgical instruments are placed. However, the devices are limited in that the positions of the simulated surgical instruments are predetermined, which is not a realistic scenario. Furthermore, the visual feedback is based upon a stream of video images taken from actual surgical procedures. However, such simple rendering of video images would result in inaccurate or unrealistic images as portions of the video data would need to be removed for greater processing speed. Alternatively, the video processing would consume such massive amounts of computational time and resources that the entire system would fail to respond in a realistic time period to the actions of the student. At the very minimum, a dedicated graphics workstation would be required, rather than a personal computer (PC). Thus, neither reference teaches or discloses adequate visual processing for real time visual feedback of the simulated medical procedure.

Similarly, U.S. Patent No. 4,907,973 discloses a device for simulating the medical procedure of flexible gastro-endoscopy. The disclosed device also suffers from the deficiencies of the above-referenced background art devices, in that the visual feedback system is based upon rendering of video data taken from actual endoscopic procedures. As noted previously, displaying such data would either require massive computational resources, or else would simply require too much time for a realistic visual feedback response. Thus, the disclosed device also suffers from the deficiencies of the background art.

A truly useful and efficient medical simulation device for minimally invasive therapeutic procedures such as endoscopy would give real time, accurate and realistic visual feedback of the procedure, and would also give realistic tactile feedback, so that the visual and tactile systems would be accurately linked for the simulation as for an actual medical procedure. In addition, such a device would enable the student to manipulate tools which may be required during the performance of the actual medical procedure. Unfortunately, tools for operation with such a simulation device are not currently taught or provided by the background art, nor is the device itself taught or provided in the background art.

There is therefore a need for, and it would be useful to have, a method, a device and a system to simulate a minimally invasive medical procedure such as endoscopy, particularly with regard to the operation of tools which may be required during the performance of the actual medical procedure.

SUMMARY OF THE INVENTION

The present invention features tools for use with a system for simulating the minimally invasive medical procedure of endoscopy, particularly of flexible gastro-endoscopy. The tools support the close simulation of the actual medical procedure of endoscopy by simulating medical instruments in the context of providing tactile and visual feedback as the simulated procedure is performed on the simulated patient. In addition, the present invention features a specific mechanism for providing force feedback on the tools for a more realistic and accurate operation thereof, as well as methods for correctly calculating the forces which should be applied to the tools through such a force feedback mechanism.

The inventors of the present invention have previously overcome the deficiencies of the background art, by providing a general simulation system, method and device, for enabling students to practice the medical procedure through an accurate, realistic simulation thereof, as disclosed in published PCT Application No. WO 99/38141, filed on January 15, 1999 and incorporated by reference as if fully set forth herein. However, surprisingly the present inventors have found an improved, specific mechanism for the simulation of the operation of various tools during the medical procedure, which is described in the present application.

According to the present invention, there is provided a simulated medical tool for manipulation in a simulated organ by a user, comprising: (a) a tool body; (b) a tool handle attached to the tool body for manipulation by the user; (c) a cable contained in the tool body; (d) a negative electrode attached to the cable; and (e) a positive electrode adjacent to the cable, the positive electrode being in electrical contact with the negative electrode without physically contacting the cable, such that an electrical circuit is formed for providing potentiometric resistance on the cable.

According to another embodiment of the present invention, there is provided a system for simulating a medical procedure by a user, the system comprising: (a) a simulated organ; (b) a simulated tool for entering into the simulated organ for performing the simulated medical procedure, the simulated tool comprising: (i) a tool body; (ii) a tool handle attached to the tool body for manipulation by the user; (iii) a cable contained in the tool body; (iv) a negative electrode attached to the cable; and (v) a positive electrode adjacent to the cable, the positive electrode being in electrical contact with the negative electrode without physically contacting the cable, such that an electrical circuit is formed for providing potentiometric resistance on the cable, an amount of the resistance being proportional to a distance traveled by the cable; and (c) a visual display for providing visual feedback according to the distance traveled by the cable in the simulated organ.

According to yet another embodiment of the present invention, there is provided a simulated medical tool for manipulation in a simulated medical procedure by a user, comprising: (a) a tool body; (b) a tool handle attached to the tool body for manipulation by the user; (c) an air-based force generating system for generating a force against the tool body to provide force feedback to the user, the air-based force generating system generating the force against the tool body according to air pressure to simulate the medical procedure.

The method of the present invention for preparing a model of the simulated organ, and for rendering the visual feedback of the simulated organ during the simulated medical procedure, can be described as a plurality of instructions being performed by a data processor. As such, these instructions can be implemented in hardware, software or firmware, or a combination thereof. As software, the steps of the method of the present invention could be implemented in substantially any suitable

programming language which could easily be selected by one of ordinary skill in the art, including but not limited to, C and C++.

Hereinafter, the term "simulated medical procedure" refers to the simulation of the medical procedure as performed through the system and method of the present invention. Hereinafter, the term "actual medical procedure" refers to the performance of the medical procedure on an actual, living human patient with an actual endoscope, such that the medical procedure is "real" rather than "simulated". Hereinafter, the term "corresponding actual organ" refers to the "real" organ of a human being or other mammal which is being simulated by the simulated organ of the present invention.

Hereinafter, the term "endoscopy" includes, but is not limited to, the procedure of flexible gastro-endoscopy, as previously described, and medical diagnostic and surgical procedures in which an endoscope is inserted into the mouth or the rectum of the subject for manipulation within the gastro-intestinal tract of the subject. Hereinafter, the term "subject" refers to the human or lower mammal upon which the method and system of the present invention are performed or operated. Hereinafter, the term "student" refers to any human using the system of the present invention, being trained according to the present invention or being taught according to the present invention including, but not limited to, students attending medical school or a university, a medical doctor, a trained gastro-enterologist or other trained medical specialist.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings, wherein:

FIG. 1 is an exemplary illustration of the system for medical simulation according to the present invention;

FIG. 2 shows the visual processing and display system of Figure 1 in more detail;

FIGS. 3A and 3B are schematic block diagrams of the simulated biopsy device of the present invention;

FIG. 4 is a cut-away side view of a preferred embodiment of the simulated biopsy device of Figures 3A and 3B;

FIGS. 5A-5D are detailed views of portions of the device of Figure 4; and

FIG. 6 is a schematic diagram of a cut-away view of an exemplary but preferred implementation of the force feedback mechanism for the tools according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention features tools for use with a system for simulating the minimally invasive medical procedure of endoscopy, particularly of flexible gastro-endoscopy. The tools support the close simulation of the actual medical procedure of endoscopy by simulating medical instruments in the context of providing tactile and visual feedback as the simulated procedure is performed on the simulated patient.

The tool of the present invention is described in the preferred exemplary embodiment of a simulated biopsy device, although clearly other tools could also be simulated. The present invention is able to provide physical and visual feedback through the use of potentiometry, which involves an electrical current to generate resistance on the simulated tool.

According to preferred embodiments of the present invention, potentiometric resistance is provided on a flexible, moving object, such as the flexible cable of the biopsy device, without attaching the entire electrical supply directly to the cable. Instead, one electrode (shown below as the negative electrode) is attached directly to the cable, while the other electrode (shown below as the positive electrode) is attached indirectly, to a wire wrapped around the cable. Thus, both electrodes are provided without directly attaching both to the flexible cable.

The present invention enables linear potentiometric resistance to be generated on the flexible cable of the simulated biopsy device, which is important both for accurately determining the resistance which is required, and for determining the distance which has been traveled by the flexible cable. The traveled distance is preferred for providing accurate visual feedback, in terms of the relative location of the simulated biopsy device within the simulated gastro-intestinal tract and/or endoscope of the present invention.

The principles and operation of the present invention may be better understood with reference to the drawings and the accompanying description, it being understood

that these drawings are given for illustrative purposes only and are not meant to be limiting. Furthermore, although the description below is directed toward the simulation of the colon, it should be noted that this is only for the purposes of clarity and is not meant to be limiting in any way.

Referring now to the drawings, Figure 1 depicts an exemplary, illustrative system for medical simulation for use with the tools according to the present invention. A system **10** includes a mannequin **12** representing the subject on which the procedure is to be performed, a simulated endoscope **14** and a computer **16** with a video monitor **18**. A student **20** is shown interacting with system **10** by manipulating simulated endoscope **14** within mannequin **12**. Mannequin **12** includes a simulated organ into which simulated endoscope **14** is inserted. As student **20** manipulates simulated endoscope **14**, tactile and visual feedback are determined according to the position of endoscope **14** within the simulated organ (not shown). The visual feedback are provided in the form of a display on video monitor **18**. The necessary data calculations are performed by computer **16**, so that realistic tactile and visual feedback are provided to student **20**.

As shown with regard to Figure 2, the system of Figure 1 provides a solution to a number of problems in the art of medical simulation, in particular for the simulation of the procedure of gastro-endoscopy. This procedure involves the visual display of an interior portion of the gastrointestinal tract, such as the colon. The colon is a flexible body with a curved structure. The inner surface of the colon is generally deformable, as well as being specifically, locally deformable. All of these deformations in space must be calculated according to the mathematical model of the colon, and then rendered visually in real time in order to provide a realistic visual feedback response for the user.

Figure 2 shows the visual processing and display system of Figure 1 in more detail. A visual processing and display system **40** includes screen display **22** for displaying the processed visual data. The visual data are constructed as follows. First, data are recorded from actual gastro-endoscopic procedures onto videotape, as shown in a recording block **42**. The data are preferably stored on Super-VHF videotape in order to obtain the highest quality representation of the visual images displayed on the screen during the actual endoscopic procedure, as shown in block **44**. Next, at least a

portion of the frames of the videotape, and preferably substantially all the frames, are abstracted individually by a frame-grabber **46** to form digitized images. Individual digitized images can then be selected for clarity and lack of artifacts such as reflections from the endoscopic apparatus itself. The images in the selected frames are then preferably enhanced and added to a texture mapping database **48**.

Preferably, two types of texture mapping are stored in the database. The first type of texture mapping is intended to enhance the realistic visual aspects of the images, for example by removing visual artifacts. The second type of texture mapping is intended to simulate the behavior of a live organ and a real endoscope, as represented by block **50**. During actual endoscopic procedures on a living human patient, the tissue of the colon moves somewhat, and the endoscope itself vibrates and wobbles. This movement is simulated visually by the addition of random animation of the images, and also by the addition of such effects as liquid flowing downward due to the influence of gravity. Such animation enhances the realistic nature of the visual representation of the colon.

In order for the enhanced images to be correctly displayed, the images must correspond to the manipulation and location of the simulated endoscope within the simulated colon. In particular, the texture mapping of the images should correspond to the location of the endoscope within the colon. Such correspondence between the location of the endoscope within the colon and the texture mapping is provided by a texture mapping engine **52**. The texture mapping data is then readily accessed by the display portion of visual system **40**, as shown by block **54**.

However, as noted for previous background art devices, simply reproducing the selected enhanced frames in a massive video stream would quickly overwhelm the computational resources and cause the visual display to become unsynchronized from the physical location of the simulated endoscope. Furthermore, such a video stream would not enable the correct display of images according to the movement of the endoscope, which preferably has six degrees of freedom. Thus, mere reproduction is not sufficient to ensure realistic images, even when mapped onto a three-dimensional surface.

Preferably, visual processing and display system **40** includes a three-dimensional mathematical model of at least a portion of the gastro-intestinal tract

56. For the purposes of discussion, model **56** is herein described as a three-dimensional model of the colon, it being understood that this is not meant to be limiting in any way. Model **56** preferably features a plurality of segments **58**, more preferably many such segments **58**.

As the simulated endoscope moves along the simulated colon, the location of the endoscope is given to a locator **60**, described in further detail below. Locator **60** then instructs an object loader **62** to load the relevant segment **58** for access by visual system **40**, as shown in block **54** and previously described. In the preferred embodiment shown, preferably three segments **58** are ready for access by object loader **62** at any given moment. The specific segment **58** in which the endoscope is currently located is preferably held in DRAM or RAM, in combination with the texture mapping described previously. The next segment **58** and the preceding segment **58** preferably are also stored in an easily accessible location, although not necessarily in RAM or DRAM.

Preferably, the display of each image from specific segment **58** into which the simulated endoscope has entered is optimized by a segment optimizer **64**. Segment optimizer **64** receives information from locator **60**, as well as the series of images obtained from overlaying the texture mapping onto the relevant segment **58**, and then feeds each specific image to a display manager **66** for display on screen display **22**.

In addition, display manager **66** is assisted by a real-time viewer **68**, preferably implemented in Direct 3D™ (Microsoft Corp., USA). Real-time viewer **68** provides the necessary software support to communicate with a graphics card **70** for actual display of the images on screen display **22**. Although graphics card **70** can be of any suitable manufacture, preferably graphics card 70 has at least 8, and more preferably at least 16, Mb of VRAM for optimal performance. An example of a suitable graphics card **70** is the 3Dfx Voodoo Rush™ card. Preferably, the performance of real-time viewer **68** is enhanced by a math optimizer **72**, preferably implemented in Visual C++.

The interaction between segment optimizer **64** and display manager **66** on the one hand, and locator **60** on the other, is provided through a software interface **74**, preferably implemented as a Direct Plug-in™ (Microsoft Corp, USA). Software interface **74** enables locator **60** to communicate with the other components of visual

system **40**, in order to provide information regarding the location of the endoscope within the colon.

In preferred embodiments, locator **60** includes a sensor **76**, which can be obtained from Ascension Technology Corp., for example. Sensor **76** senses positional information from within a simulated organ 77, which is described herein as a colon for the purposes of discussion and is not meant to be limiting. Sensor **76** is controlled by a control unit **82**. The positional information is then relayed to a CPU controller **78**, which is connected to a servo-motor **80** (Haydon Switch and Instrument Co.). As the simulated endoscope moves through the colon, the endoscope contacts different portions of the colon. Tactile feedback is provided by each servo-motor **80** in turn, which manipulates the material of the colon.

Visual system **40** also includes a user interface **84**, preferably implemented in Visual C++. User interface **84** enables visual system **40** to interact with the preferred feature of a network interface **86**, for example, so that other students can view screen display **22** over a network. User interface **84** also permits the tutorial functions of at least one, and preferably a plurality of, tutorial modules **88** to be activated. Tutorial module **88** could include a particular scenario, such as a subject with colon cancer, so that different types of diagnostic and medical challenges could be presented to the student. The student would then need to respond correctly to the presented scenario.

Figures 3A and 3B are schematic block diagrams of an exemplary tool, a simulated biopsy device, for use with the system of Figure 1 or another such system. This biopsy device would simulate the actual biopsy device used to retrieve tissue samples from the gastro-intestinal tract during endoscopy. The actual biopsy device is contained within the endoscope. When the operator of the endoscope wishes to take a sample, the biopsy device emerges from the tip of the endoscope, at which point it is visible on the display screen. The jaws of the biopsy device are then opened and pushed onto the tissue. The jaws are then closed, and the biopsy device retracted. The removal of the tissue causes pools of blood to appear as the remaining tissue bleeds.

Similarly, the simulated biopsy device only appears on the display screen of the system of Figure 1 when the operator of the simulated endoscope causes the simulated biopsy device to emerge. The jaws of the biopsy device are preferably rendered as animation, more preferably in relatively high resolution because the jaws are small, so

that a high resolution would not prove unduly taxing for the computer. The bleeding of the tissue and the resultant pools of blood are also be animated.

As shown with regard to Figures 3A and 3B, the simulated biopsy device of the present invention features a relatively minimal adaptation of an existing medical tool. These changes enable both tactile force feedback to be provided and the relative location of the simulated device within the simulated colon to be determined, thereby enabling both the physical and visual aspects of the medical procedure to be simulated.

Figure 3A is a schematic block diagram of a simulated biopsy device **100** in a retracted position. As shown, simulated biopsy device **100** features a tool body **102**, to which a mobile handle **104** is attached. The human operator moves mobile handle **104** in a lateral direction, such that mobile handle **104** is displaced. The displacement of mobile handle **104** causes a flexible cable **106**, to which mobile handle **104** is attached, to be moved. The movement of flexible cable **106** in turn causes the position of a biopsy loop **108** to be displaced in the lateral direction.

The lateral displacement of biopsy loop **108** in turn determines whether simulated biopsy device **100** is in the retracted position with regard to a simulated endoscope **110**, as shown in Figure 3A, or alternatively extended into simulated endoscope **110**, as shown in Figure 3B. When the human operator wishes to position biopsy loop **108** for performing a simulated biopsy procedure, biopsy loop **108** is extended into simulated endoscope **110**. Suitable visual and tactile feedback must then be provided for the performance of the simulated biopsy procedure.

Simulated biopsy device **100** preferably provides such force feedback through potentiometry, which is the use of electrical current to generate and adjust physical resistance. Potentiometry has a number of advantages over the use of mechanical components to provide such physical resistance, including the greater ability to adjust the resistance through potentiometry; the reduction in the number of mechanical moving parts which are required; and decreased physical wear on the simulated tool. Thus, potentiometry is particularly preferred for providing tactile, force feedback for the simulated tool of the present invention.

As shown in Figure 3B, potentiometric resistance is provided by passing an electrical current through simulated biopsy device **100**. The electrical current is supplied through an electrical supply **112**, which is connected to flexible cable **106**.

The amount of current is preferably adjusted in order to provide finely tuned physical feedback, by adjusting resistance on simulated biopsy device **100**.

Unfortunately, potentiometry has one drawback: it is extremely difficult to provide potentiometric resistance on a flexible, moving object, as potentiometry requires an electrical current to be passed through the object. There is no solution which is known in the background art for this problem

The simulated tool of the present invention solves this problem, as shown in Figure 4, by not directly attaching the entirety of electrical supply **112** to flexible cable **106**. Instead, as shown in greater detail with regard to Figure 5A, only a negative electrode **114** is attached to flexible cable **106**. Negative electrode **114** is held in place with a first screw **116** and a second screw **118**, which hold a clamp **120** against flexible cable **106**. The entire assembly is held within a tube **122**.

A positive electrode **124** is shown in Figures 4 and 5B. A pin **126** is held in place with a contactor **128**. This assembly in held in place with screws **118**. Electricity is passed through pin **126** to contactor **128**, which does not contact flexible cable **106** directly. Instead, as shown with regard to Figure 5C, electricity is preferably passed indirectly, to a spiral wire **130** which is wrapped around flexible cable **106**. Spiral wire **130** is preferably made from a chrome-nickel alloy, and more preferably has a thickness of about 0.08 mm. In comparison, flexible cable **106** preferably has a thickness of about 1.1 mm. The relatively thinness of spiral wire **130** enables positive electrode **124** to be easily added to an existing medical device in order to form the simulated tool of the present invention. Spiral wire **130** is preferably held against flexible cable **106** by tubing **132**, which could be Teflon™ for example.

Positive electrode **124**, and more particularly contactor **128**, is preferably held in place within mobile handle **104** by a spring **134**, as shown with regard to Figure 4.

According to a preferred embodiment of the present invention, as shown in Figure 5D, biopsy loop **108** is preferably implemented as a straight cable **136**. Straight cable **136** is preferably contained within a guide **138**, for attaching simulated biopsy device **100** to the simulated endoscope (not shown). This assembly is preferably further held in place with a spring pad **140**, and a clamp **142**.

The present invention provides potentiometric resistance on a flexible, moving object, which had not been previously known in the background art. In addition, the

present invention has the advantage of providing such resistance in a linear manner, such that the amount of resistance is linear over the length of flexible cable **106**. The amount of resistance is optionally determined by receiving the analog electrical signal, and converting the signal to digital output. The digital output can then optionally be used with the computer of Figures 1 and 2, for example in order to determine the distance which has been traveled by flexible cable **106**.

The linearity of such resistance is important for a number of reasons. First, the distance which flexible cable **106** has traveled is directly proportional to the amount of resistance. The determination of such distance is important for the simulation of the medical procedure, since the provision of suitable visual feedback depends upon determining the location of flexible cable **106** within the simulated endoscope and/or gastro-intestinal tract. Second, the provision of linear resistance enables the amount of resistance to be finely determined in a highly sensitive manner. Thus, the preferred provision of linear resistance is highly useful.

Figure 6 is a schematic diagram of a cut-away view of an exemplary but preferred implementation of the force feedback mechanism for the tools according to the present invention. In this implementation, the force feedback is provided through a mechanical device as shown, rather than through the generation of resistance through the application of an electric current. It is understood that some combination of both of these different types of force feedback systems could also optionally be used.

As shown, a simulated endoscope **200** features a tool port **210** for the insertion of a simulated tool **220**. Preferably, simulated tool **220** is highly similar in appearance to the corresponding actual medical tool, optionally with the exception of some identifying marking on simulated tool **220** so as to prevent confusion. Simulated tool **220** preferably features a cable **230** for insertion into simulated endoscope **200** through tool port **210**. The student or other user then operates simulated tool **220** during the simulated medical procedure, for example according to visual feedback received through a video monitor (not shown).

Force feedback is provided on simulated tool **220** through an air-based force generating system **240**, which optionally and preferably generates such force against cable **230**. Air-based system **240** preferably features an air balloon **250** which presses against cable **230**, such that the degree of inflation of air balloon **250** determines the

amount of force which is applied against cable **230**. Air balloon **250** is in turn connected to an air-supply pipe **260** within simulated endoscope **200**. Air-supply pipe **260** is then connected to a force-feedback air supply **270**. Thus, the degree of inflation of air balloon **250** is determined according to the amount of air supplied by force-feedback air supply **270**.

In turn, the activity of force-feedback air supply **270** is more preferably controlled by a computational device **280**, which operates an air supply control module **290**. Air supply control module **290** preferably calculates the required forces which should be applied to simulated tool **220** through air balloon **250**, and then determines the amount of air which should be supplied to air balloon **250** from force-feedback air supply **270**.

Generally, these forces may be described as having both an amount and a direction. The forces themselves result from the requirement to simulate events during the simulation; for example, the "collision" of simulated tool **220** with an organ of the body of the subject (not shown). This collision does not need to occur, but any force(s) which would have been generated if the collision had occurred in the body of a living subject do need to be calculated.

In order for the calculation to be accurate, each tool and each organ to be simulated need to be described according to a set of physical specifications, such as size, resiliency, and so forth. For certain activities, such as cutting a portion of an organ for a biopsy, for example, the tissue of the organ would change geometrical shape, which would also affect the forces being generated. Also, the velocity and direction of tool movement need to be considered, in order to create a vector of forces generated by the tool itself. However, as a simplification of these calculations, more preferably, forces generated on the tool, and by the tool, are considered to be linear forces. Such a simplification is still accurate when the actual tool features a long cable which must be inserted into the actual endoscope, as the length of the cable effectively renders the forces only as linear forces.

The procedure for calculating the force involved for the force feedback is preferably performed as follows, with regard to the illustrative, but non-limiting, example of a tool colliding with an organ. The tool has a first velocity before the collision, and a second velocity after the collision. The second velocity is preferably

calculated according to a simulation model, and more preferably includes physical parameters of the tool and of the organ itself, such as resiliency for example. The force is then computed according to the difference in velocity, times the mass of the tool:

$$f = m\,(v1-v2)$$

in which *f* is the force to be applied as force feedback; *m* is the mass of the tool; *v1* is the first velocity (before the collision); and *v2* is the second velocity (after the collision). The air pressure in air balloon **250** is then preferably adjusted, by increasing or decreasing the amount of air in air balloon **250**, in order to create the correct amount of force as force feedback.

More preferably, the calculation of the force is expanded to include a plurality of forces which should be generated against simulated tool **220**. For example a first force could optionally be the result of a collision between the tool and an organ, while the second force could optionally be the result of cutting a portion of another organ with this same tool. These forces are more preferably all accurately represented in the simulation, and as such should more preferably be accurately applied to simulated tool **220**. Therefore, these forces are preferably calculated for a specific tool with all organs in the simulation at any given point in time, and are then summed in order to determine the relative air pressure in air balloon **250**, as shown with regard to the following equation:

$$AP \sim \Sigma\, Fi$$

in which *AP* is the air pressure and *Fi* is the *i*th force against the tool.

It will be appreciated that the above descriptions are intended only to serve as examples, and that many other embodiments are possible within the spirit and the scope of the present invention.

WHAT IS CLAIMED:

1. A simulated medical tool for manipulation in a simulated organ by a user, comprising:

(a) a tool body;

(b) a tool handle attached to said tool body for manipulation by the user;

(c) a cable contained in said tool body;

(d) a negative electrode attached to said cable; and

(e) a positive electrode adjacent to said cable, said positive electrode being in electrical contact with said negative electrode without physically contacting said cable, such that an electrical circuit is formed for providing potentiometric resistance on said cable.

2. The tool of claim 1, wherein a location of said cable within said tool body is adjusted according to manipulation of said tool handle, said tool handle being connected to said cable.

3. The tool of claim 2, wherein said location is determined according to an amount of resistance on said cable.

4. The tool of claim 1, wherein said positive electrode further comprises a wire wrapped around said cable, without physically touching said cable.

5. A system for simulating a medical procedure by a user, the system comprising:

(a) a simulated organ;

(b) a simulated tool for entering into said simulated organ for performing the simulated medical procedure, said simulated tool comprising:

(i) a tool body;

(ii) a tool handle attached to said tool body for manipulation by the user;

(iii) a cable contained in said tool body;

(iv) a negative electrode attached to said cable; and

(v) a positive electrode adjacent to said cable, said positive electrode being in electrical contact with said negative electrode without physically contacting said cable, such that an electrical circuit is formed for providing potentiometric resistance on said cable, an amount of said resistance being proportional to a distance traveled by said cable;

and

(c) a visual display for providing visual feedback according to said distance traveled by said cable in said simulated organ.

6. A simulated medical tool for manipulation in a simulated medical procedure by a user, comprising:

(a) a tool body;

(b) a tool handle attached to said tool body for manipulation by the user;

(c) an air-based force generating system for generating a force against said tool body to provide force feedback to the user, said air-based force generating system generating said force against said tool body according to air pressure to simulate the medical procedure.

7. The tool of claim 6, wherein said air-based force generating system further comprising:

(i) an air balloon for generating said force against said tool body; and

(ii) a force-feedback air supply for determining said air pressure in said air balloon.

8. The tool of claim 7, wherein said air pressure in said air balloon is calculated according to an amount of force generated against an actual tool in an actual medical procedure.

9. The tool of claim 7, wherein said tool body further comprises a cable for being contained in said tool body and for contacting said air balloon for said force feedback.

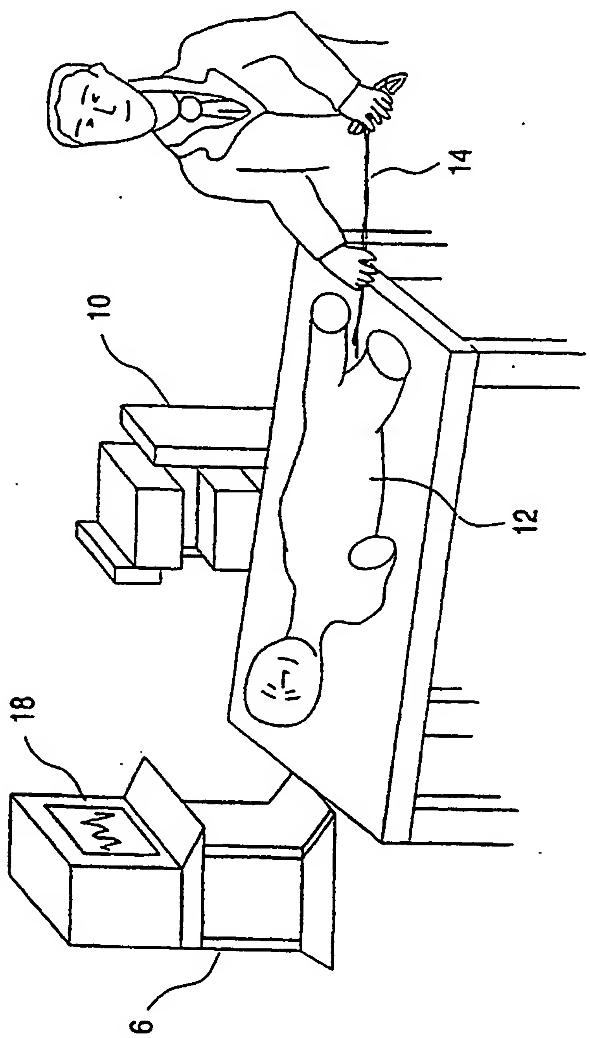
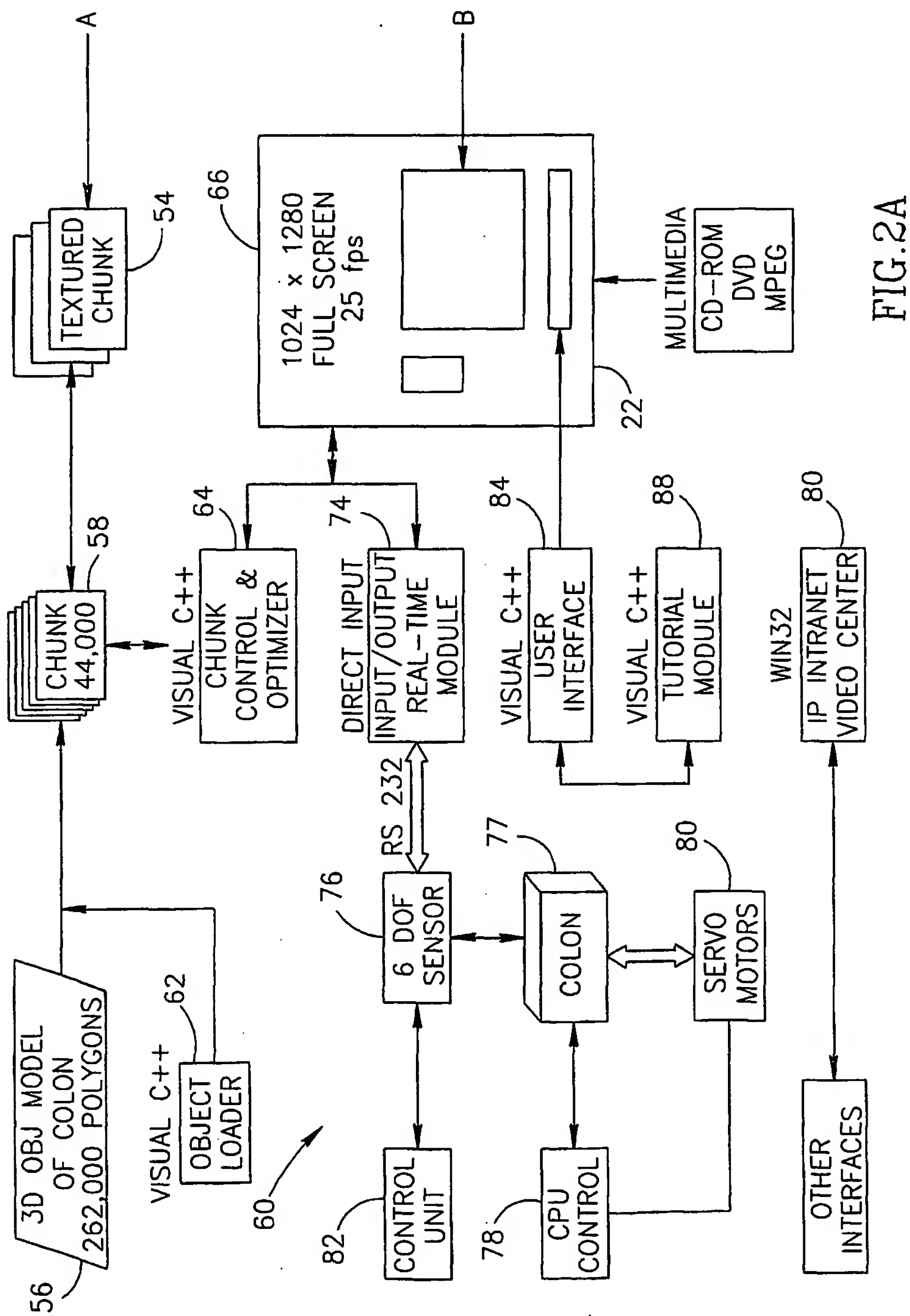


FIGURE 1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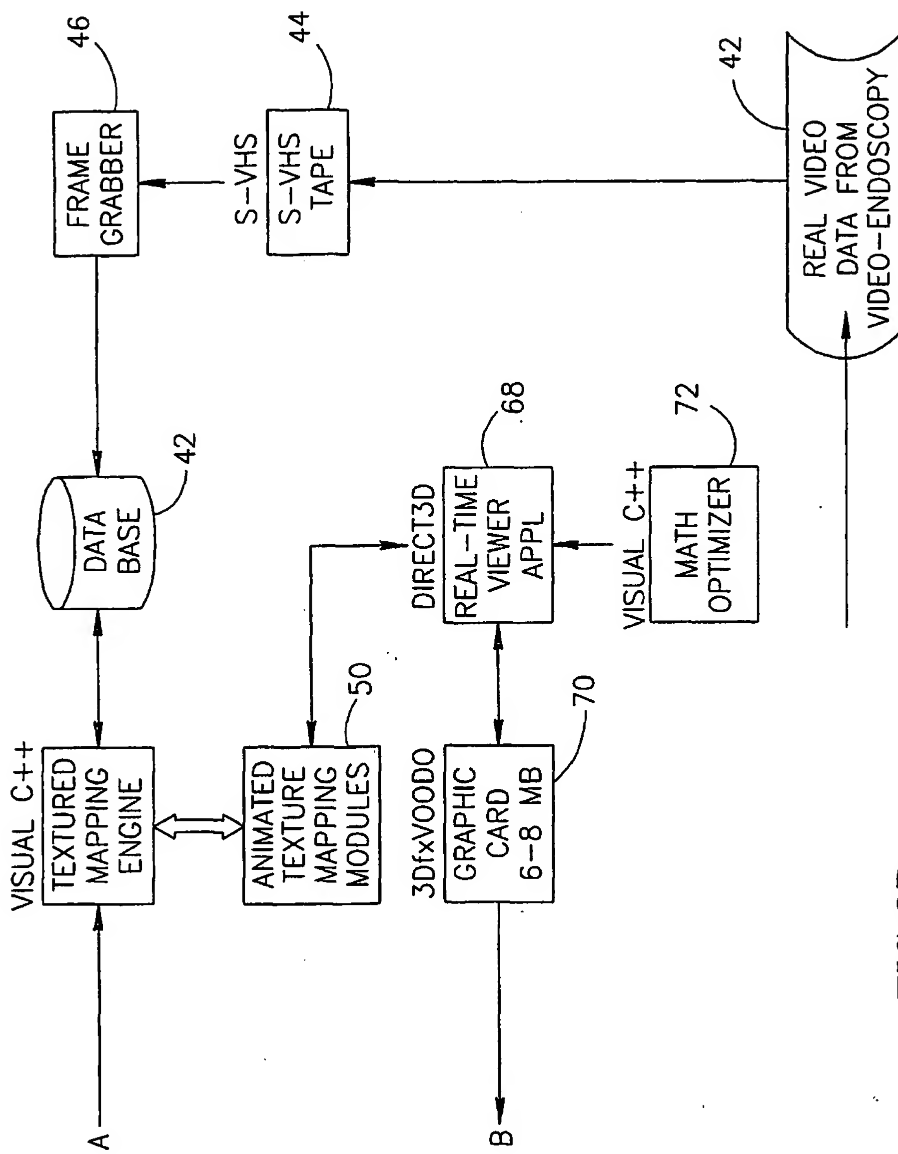
TEXTURED CHUNK
54
66
1024 x 1280
FULL SCREEN
25 fps
B
MULTIMEDIA
CD-ROM
DVD
MPEG
22
CHUNK 44,000
58
VISUAL C++
CHUNK CONTROL & OPTIMIZER
64
DIRECT INPUT
INPUT/OUTPUT REAL-TIME MODULE
74
VISUAL C++
USER INTERFACE
84
VISUAL C++
TUTORIAL MODULE
88
WIN32
IP INTRANET VIDEO CENTER
80
RS 232
76
6 DOF SENSOR
77
COLON
80
SERVO MOTORS
3D OBJ MODEL OF COLON 262,000 POLYGONS
56
VISUAL C++
OBJECT LOADER
62
60
CONTROL UNIT
82
CPU CONTROL
78
OTHER INTERFACES

FIG.2A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S-VHS
S-VHS TAPE
44
REAL VIDEO DATA FROM VIDEO-ENDOSCOPY
42
DATA BASE
42
DIRECT3D
REAL-TIME VIEWER APPL
68
VISUAL C++
MATH OPTIMIZER
72
VISUAL C++
TEXTURED MAPPING ENGINE
ANIMATED TEXTURE MAPPING MODULES
50
3DfxVOODO
GRAPHIC CARD 6-8 MB
70
A
B

FIG.2B

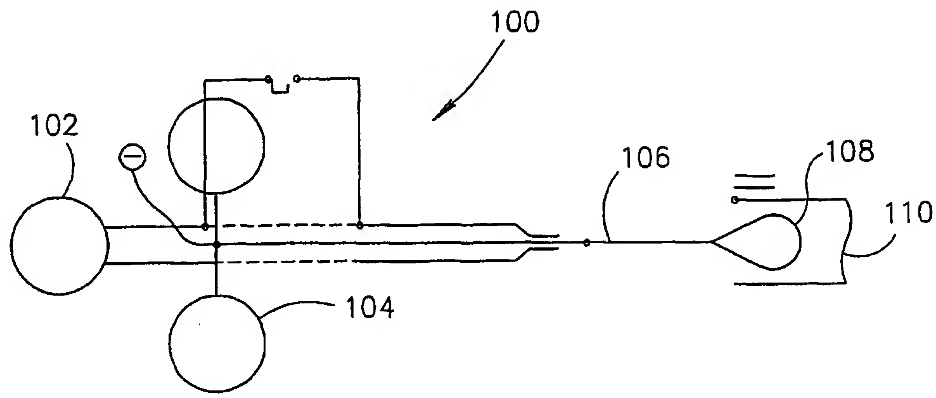

FIG.3A

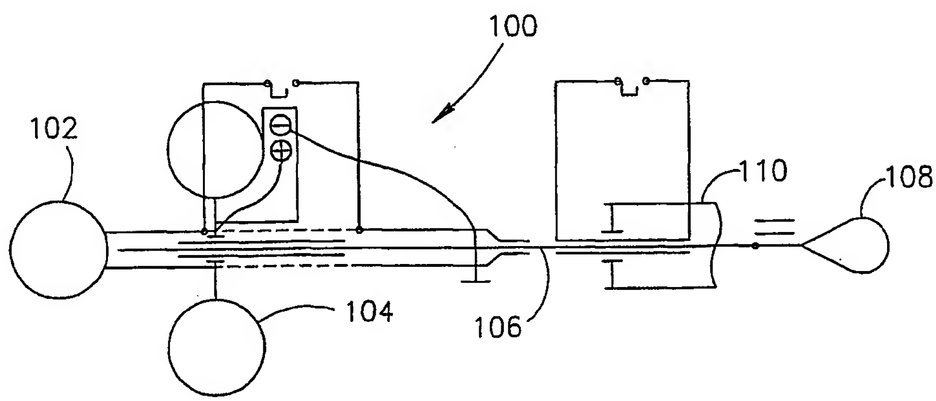

FIG.3B

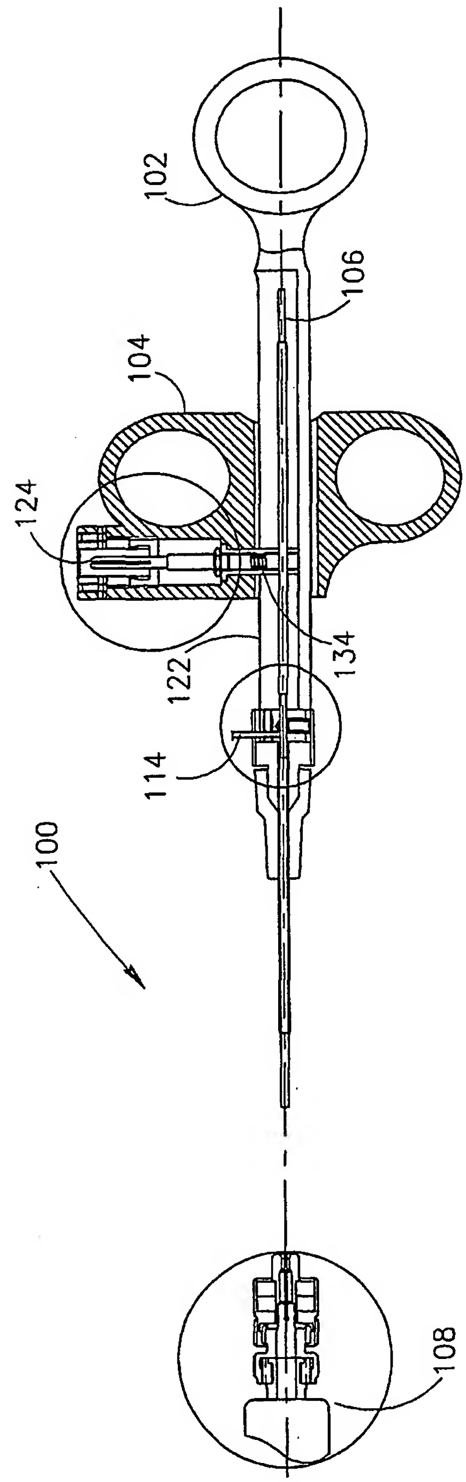

FIG.4

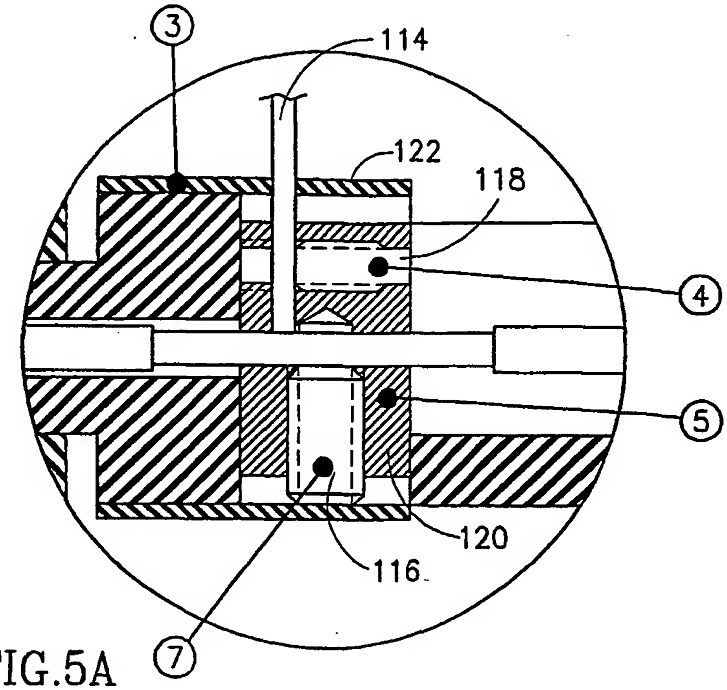

FIG.5A

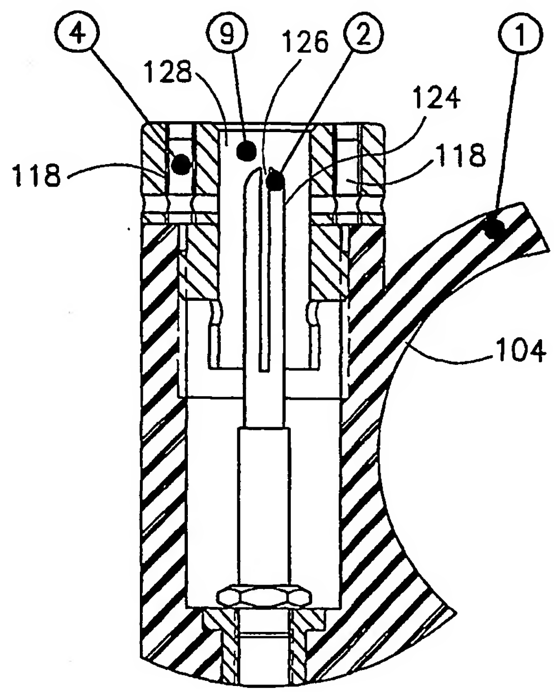

FIG.5B

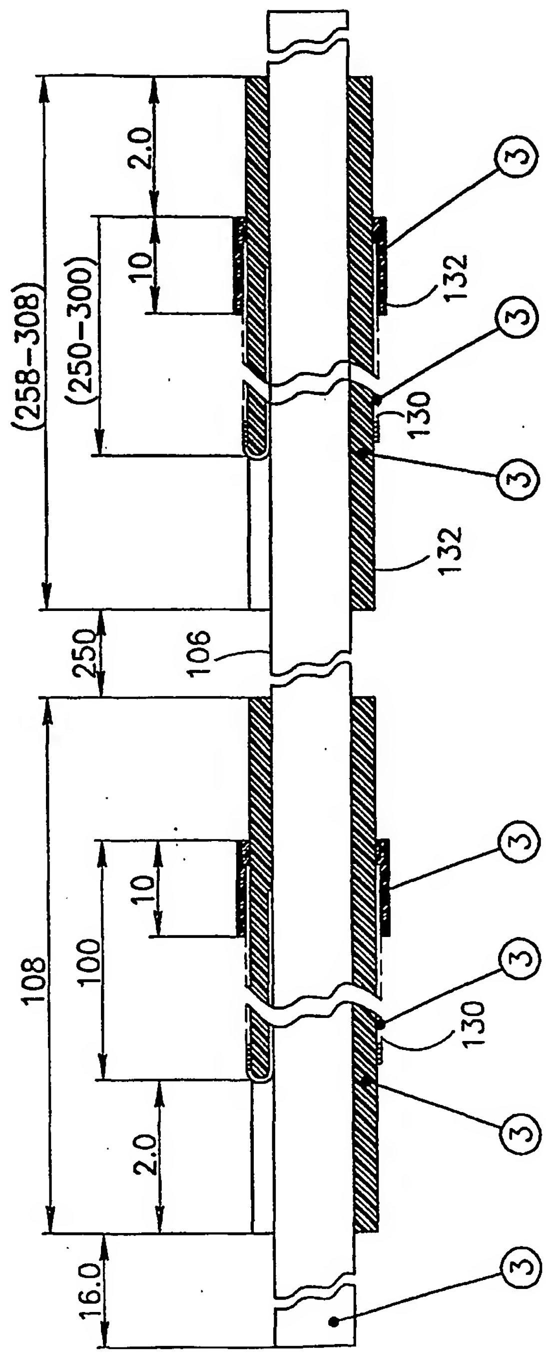

FIG.5C

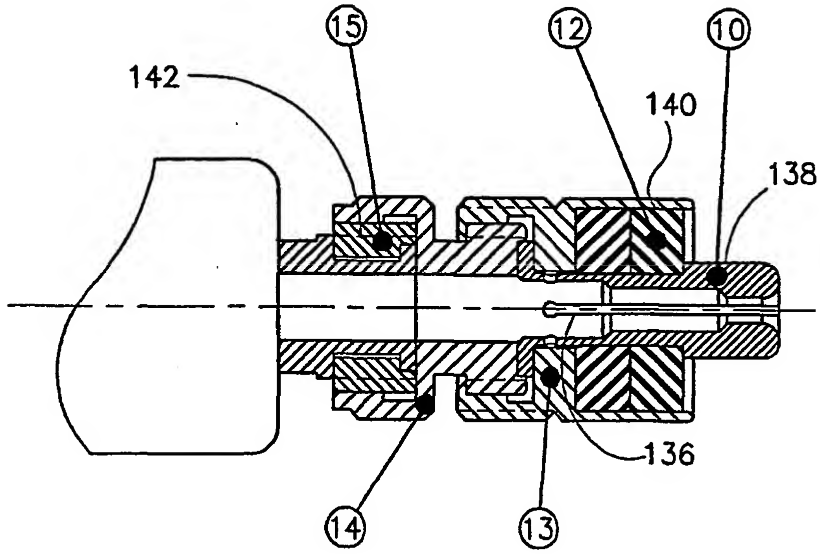

FIG.5D

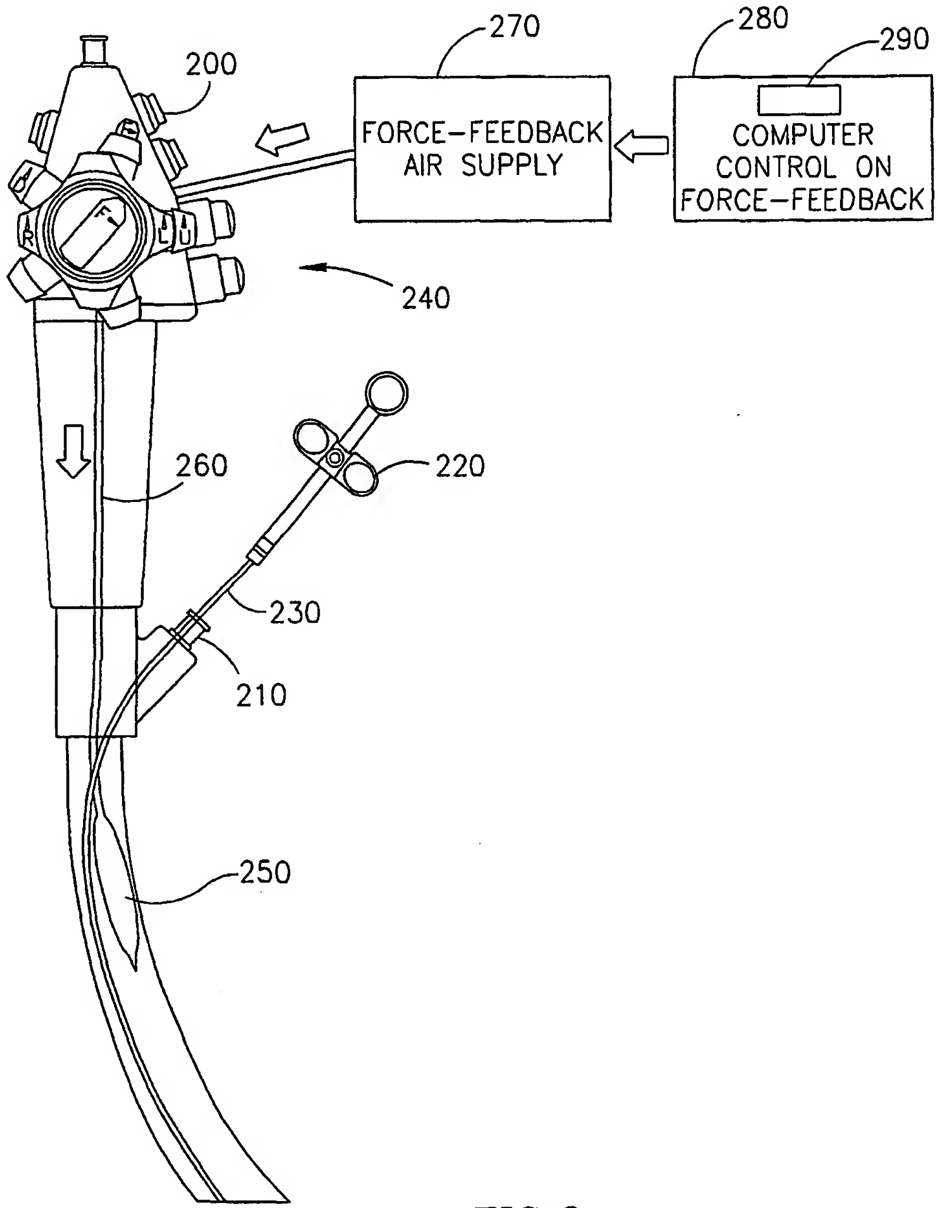
270
280
290
200
FORCE-FEEDBACK
AIR SUPPLY
COMPUTER
CONTROL ON
FORCE-FEEDBACK
240
260
220
230
210
250

FIG.6